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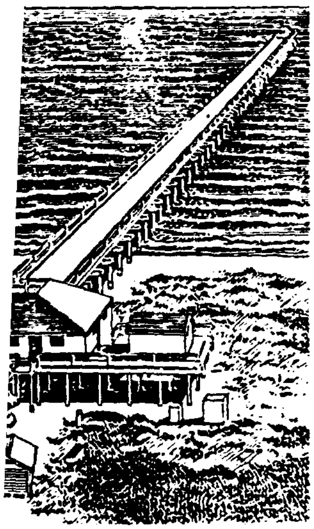

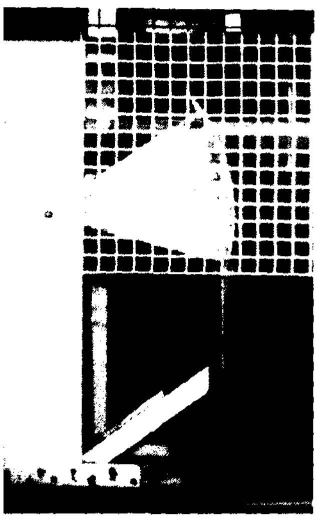

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WAVE REFLECTION AT TAINTER GATES

Hydraulic Model Investigation

by

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The design of tainter gates includes wave pressure calculations using the superposition of the incident and perfectly reflected wave at the front face of the gate. However, waves are not expected to be perfectly reflected, since wave energy is dissipated on the curved front face of the gate and lost due to overtopping of the gate. This report documents a study in which wave reflection and water surface elevations above the gate were measured in a wave tank at a 1:30 model scale for four wave conditions at three water levels each. The resulting data are to be used to reevaluate the design calculations for wave forces on tainter gates. In the study, reflection coefficients ranged from 0.42 to 0.93 and were highest at the lowest water level tested. Maximum water surface elevation occurred at a water level slightly below the tainter gate crest. The combination of water elevation, wave period, and wave reflection contributed to the higher elevation.

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PREFACE

The model investigation described herein was requested by the US Army Engineer District, Omaha (CEMRO), and funding was granted in CEMRO Military Interdepartmental Purchase Request No. ENH 0654, dated 25 July 1990.

Model tests were conducted at the US Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center (CERC), during August 1990 under the general direction of Dr. James R. Houston, Director, CERC, and Mr. Charles C. Calhoun, Jr., Assistant Director, CERC; and under the direct supervision of Mr. C. E. Chatham, Chief, Wave Dynamics Division, and Mr. D. D. Davidson, Chief, Wave Research Branch (WRB). The model investigation was conducted by Messrs. Ernest R. Smith, WRB, and C. Ray Herrington, WRB, assisted by Messrs. David A. Daily, Instrumentation Services Division, and Leland Hennington, WRB. This report was prepared by Messrs. Smith and Herrington and was typed by Ms. Myra E. Willis, WRB.

Liaison was maintained with Mr. Jeff McClenathan, CEMRO, by means of telephone conversations throughout the course of the model investigation.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander and Deputy Director was COL Leonard G. Hassell, EN.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	2.54	centimetres

WAVE EFFECTS ON TAINTER GATES

Hydraulic Model Investigation

PART I: INTRODUCTION

Background

1. Water discharge over spillways is controlled by various types of gates such as vertical-lift, rolling, drum, and tainter gates The choice of gate depends on the required function, safe-fail criteria, ease of operation, and cost. Tainter gates usually consist of a steel framework with a circular face, and are often used because they are comparatively light and easy to operate.

2. Part of the design of spillway gates includes the contribution of wave pressure. Wave pressure calculations are made using the superposition of incident and reflected waves at the front face of the gate. Presently, the superimposed wave height used in the spillway design calculations is the wave height from a perfectly reflected incident wave, i.e., the reflected wave height equals the incident wave height. This assumption is based on theory and proven experimental measurements (Shore Protection Manual 1984) in front of a vertical wall where the two wave conditions combine to form a standing wave system with a maximum wave height equal to twice the incident wave height. In actual situations, the standing wave height may undulate because of the finite width of the structure. However, since tainter gates have a curved face and critical calculations often occur at water levels where waves overtop the gates, wave energy is expected to be dissipated on the curved front face of the gate and lost due to overtopping of the gate.

Purpose

3. The US Army Engineer District, Omaha (MRO) requested that the Coastal Engineering Research Center at the US Army Engineer Waterways Experiment Station construct a scale model of a tainter gate and perform a wave study to determine water elevations above the gate and reflection coefficients off the gate. The model results are to be used in reevaluating the design calculations for wave forces on tainter gates.

PART II: THE MODEL

Model-Prototype Scale Relationships

4. Tests were conducted at a geometrically undistorted linear scale of 1:30, model to prototype. Scale selection was determined based on the following conditions: (a) absolute size of the tainter gate necessary to ensure preclusion of scale effects, (b) capabilities of the available test facility to produce necessary wave heights and periods at modeled water depths, and (c) the depth of water at the tainter gate. Based on Froude model law (Stevens et al. 1942) and the 1:30 scale, the following model-to-prototype relations were derived. Dimensions are in terms of length (L) and time (T).*

Characteristic	Dimension	Model:Prototype Scale Relations
Length	L	L_r* = 1:30
Area	L^2	A_r = 1:900
Volume	L^3	V_r = 1:27000
Time	T	T_r = 1:5.48

* The subscript r denotes the ratio of model to prototype.

Test Facilities and Equipment

5. Tests were conducted in a 150-ft-long, 1.5-ft-wide, 3.0-ft-high glass-walled wave tank.** The tainter gate was placed in the horizontal section of the tank, approximately 60 ft from the wave board.

6. All waves used in the study were monochromatic, of equal height and length. Waves were generated by an electronically controlled hydraulic system, which included a piston-type wave board. Displacement of the wave board was controlled by a command signal transmitted to the board by a synthesized function generator, and waves were produced by the periodic displacement of the wave board.

7. Wave data were collected by capacitance-type wave gages, sampled at 20 Hz. Four gages were used, three of which (Gages 1 to 3) were arranged immediately in front of the gate (approximately 30 to 60 ft prototype) to permit calculation of incident and reflected wave heights by the method of Goda and Suzuki (1976). Gage 4 recorded water surface elevations as near the front of the tainter gate as electronic signals would permit. Water surface elevations recorded from the gages were stored on magnetic disk and analyzed

* Symbols and abbreviations are listed in the Notation (Appendix A).
** A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

using the Time Series Analysis (TSAF) computer program (Long and Ward 1987). The TSAF program can execute several analysis operations, including down-crossing analysis, to obtain average wave height and period, and reflection analysis.

8. Free-surface water elevations above the tainter gate were obtained by reviewing 3/4-in. videotapes of the experiment. The video camera recorded wave action at or near each still-water level in the vicinity of the tainter gate. A 0.1- by 0.1-ft (3.0- by 3.0-ft prototype) grid was placed on the glass wall of the tank for a reference in analysis of the videotape.

9. Analysis of the wave gage and videotape records consisted only of data collected after the first wave had reflected off the tainter gate and before the first wave had reflected off the wave board and introduced reflections atypical of prototype conditions. Fifteen waves were analyzed before contamination of re-reflected waves off the wave board reached the study area.

Test Procedures

10. The wave facility was calibrated for the selected wave conditions prior to installation of the tainter gate. This allowed the signals to the wave board necessary to generate the required wave conditions to be established without reflected waves from the tainter gate.

11. Design wave conditions and water levels were provided by MRO (Table 1); however, one wave condition could not be reproduced in the model. The 3.0-sec, 5.7-ft wave condition could not be obtained because the generated wave approached the limiting wave steepness H/L in which H is wave height and L is wave length. The theoretical limiting wave steepness determined by Michell (1893) is $H/L = 0.142$. As waves approach the limiting wave steepness, they become unstable, and break. Therefore, the maximum wave height that could be produced with a 3.0-sec period was 4.8 ft.

Table 1
Design Wave Conditions

H ft	Wave Period T, sec	Still-Water Level* ft Referred to Mean Sea Level (MSL)
3.4	3.0	1,846, 1,850, 1,854
5.7**	3.0	"
7.5	5.0	"
12.5	5.0	"

* Elevation of the tank bottom is 1,784.64 ft MSL.
** Wave height limited to 4.8 ft due to wave steepness.

Tainter Gate Construction

12. The overall physical dimensions of the tainter gate were modeled according to specifications given for Garrison Dam located on the Missouri River (Figure 1). The bottom of the gate was located 40 ft (prototype) above the wave tank floor and supported by a vertical section of 3/4-in. marine plywood. The gate and plywood support were sealed to the glass walls of the tank to prevent leakage of incident wave energy and to prevent water from overtopped waves behind the gate from influencing the test conditions. An opening was cut in the vertical plywood section at the tank floor to allow equal heads to be maintained during the test. The opening was at a sufficient depth to prevent return flow from influencing the tests. A photograph of the installed tainter gate is shown in Figure 2.

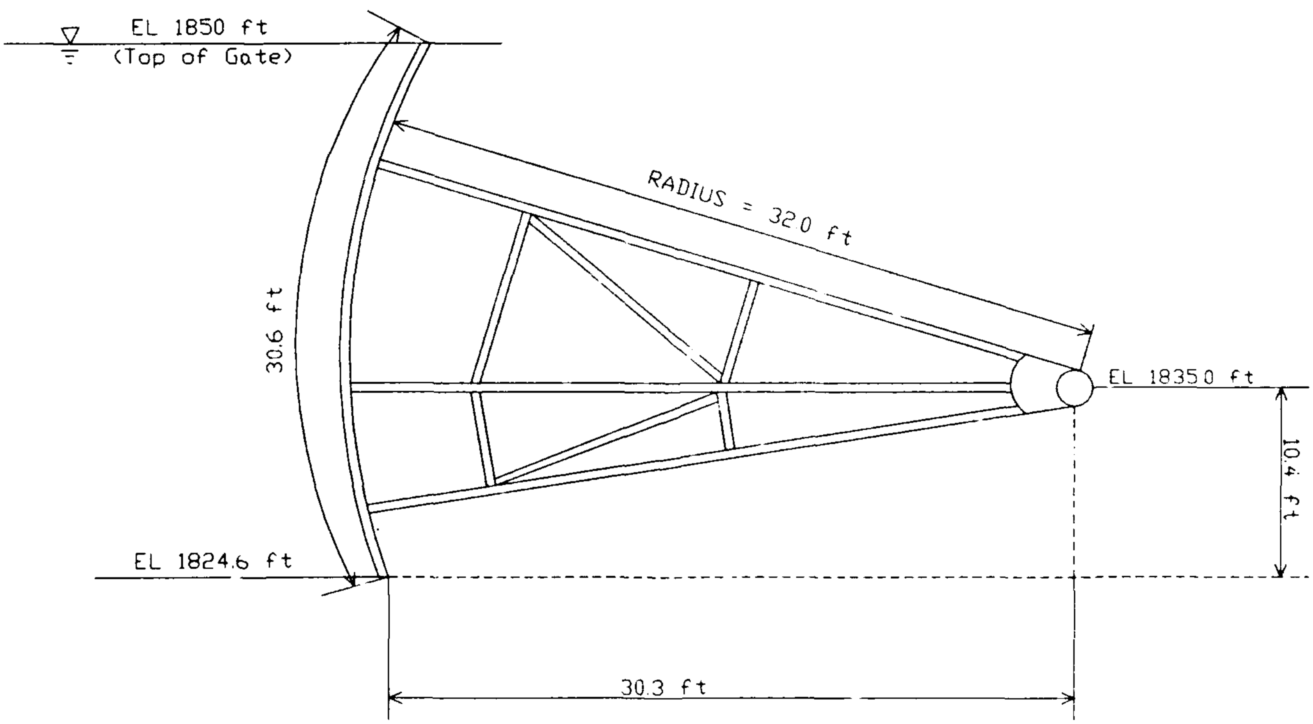

Figure 1. Physical dimensions of tainter gate at Garrison Dam

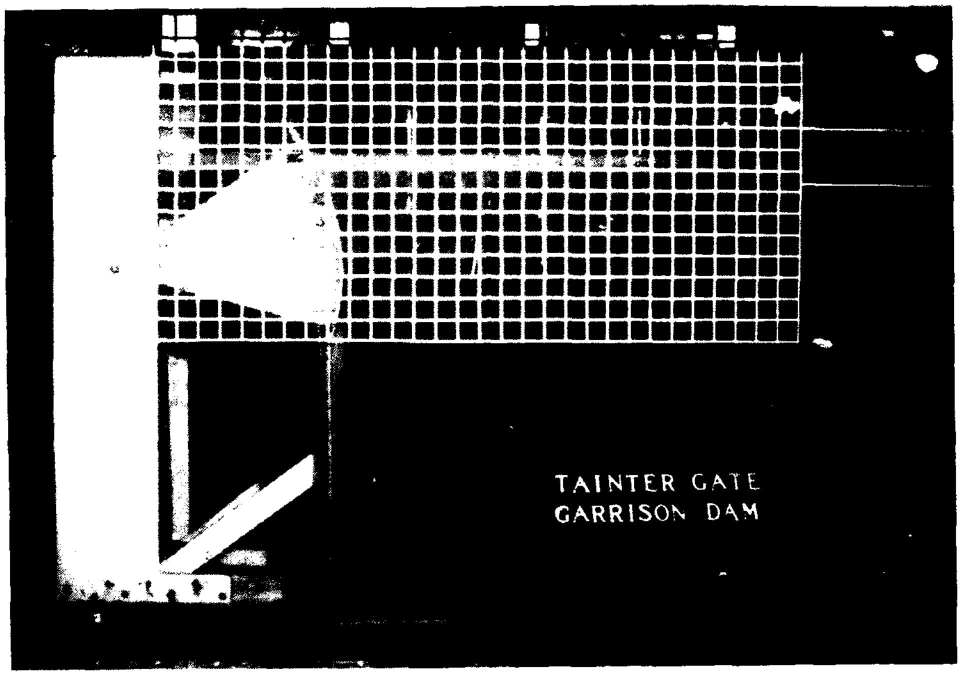

Figure 2. Photograph of tainter gate

PART III: TEST RESULTS

13. Wave reflection coefficients K_r and maximum free-surface water elevations η_{max} at the tainter gate (top elevation 1,854 ft, MSL) were determined for the test conditions. It should be noted that η_{max} is relative to MSL datum and not the still-water level (SWL) or top of the gate. Reflection was calculated from the wave records at Gages 1-3, and η_{max} from analysis of videotapes. Water level elevations measured at Gage 4 did not represent the maximum free-surface water elevation at the gate and were not used in the final analysis. Results of the experiment are shown in Table 2. Figures 3 and 4 show typical reflection and overtopping for wave conditions at SWL = 1,850 ft.

Table 2

Summary of Tainter Gate Tests

SWL* ft	T sec	H ft	K_r	η_{max} ft
1,846	3.0	3.4	0.85	1,851.0
1,846	3.0	4.8	0.82	1,854.8
1,846	5.0	7.5	0.93	1,854.0
1,846	5.0	12.5	0.85	1,857.4
1,850	3.0	3.4	0.80	1,854.0
1,850	3.0	4.8	0.77	1,855.9
1,850	5.0	7.5	0.78	1,860.0
1,850	5.0	12.5	0.66	1,865.5
1,854	3.0	3.4	0.42	1,856.2
1,854	3.0	4.8	0.42	1,857.4
1,854	5.0	7.5	0.53	1,859.2
1,854	5.0	12.5	0.51	1,863.4

* Elevation of the tank bottom is 1,784.64 ft MSL.

Wave Reflection

14. Reflection off the tainter gate was not expected to be 100 percent, $K_r = 1.0$, because of dissipation caused by the gate. The highest coefficients occurred when SWL was lowest, SWL = 1,846 ft, and overtopping was minimal. Reflection coefficients at this SWL ranged from 0.82 to 0.93. Less surface area was exposed to the front face of the wave for tests conducted at SWL = 1,850 ft, and reflection coefficients were lower, 0.66 to 0.80. At SWL = 1,854 ft, the water level was at the top of the gate, and the waves surged over the structure. Reflection coefficients ranged from 0.42 to 0.53 at SWL = 1,854 ft.

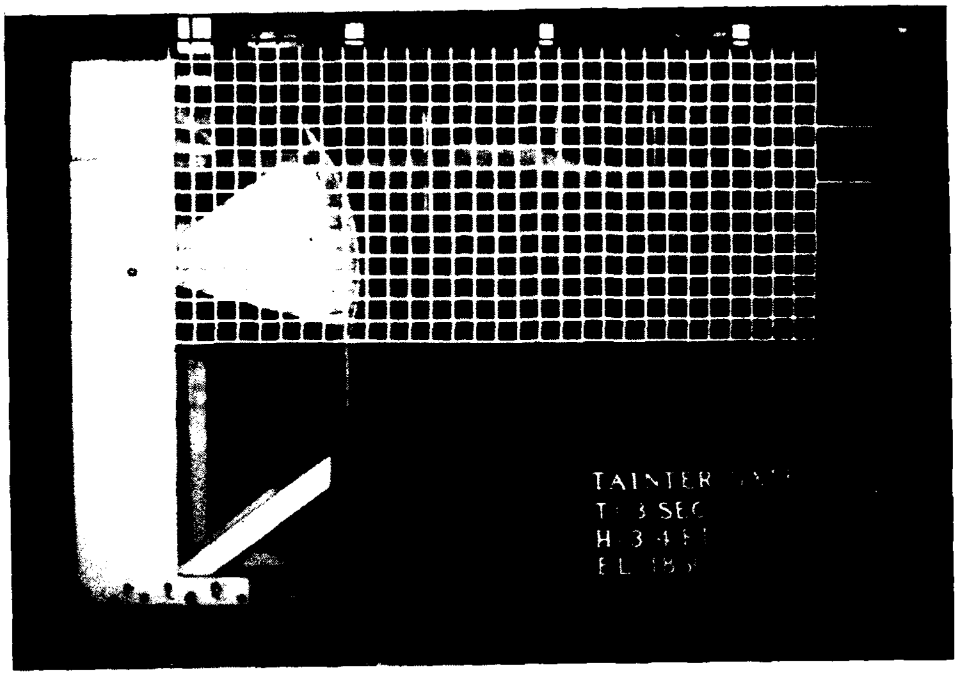

Figure 3. 3.0-sec, 3.4-ft waves, SWL = 1,850 ft

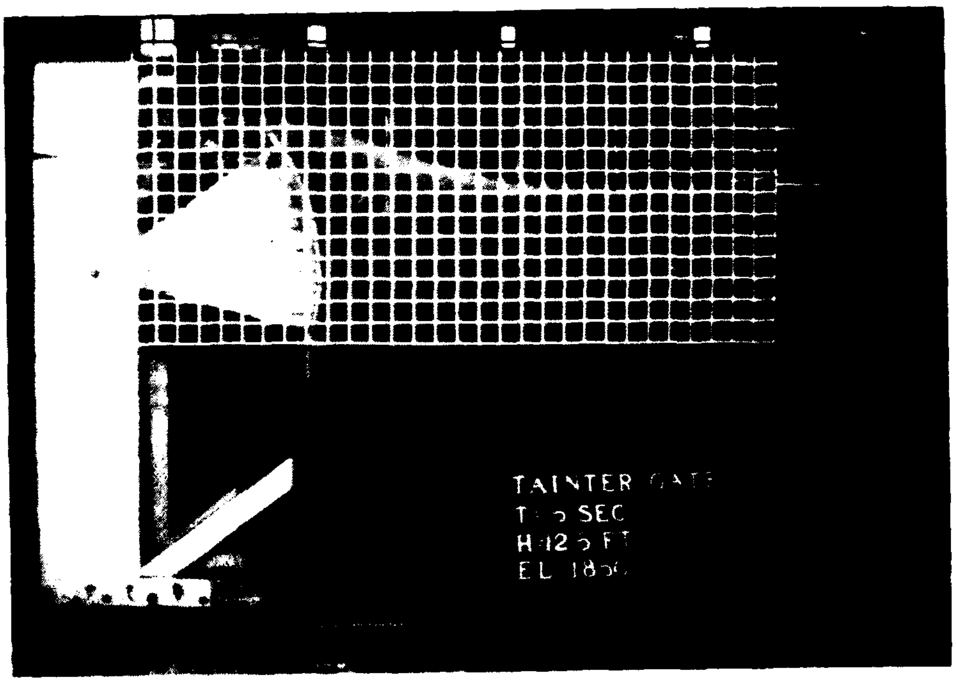

Figure 4. 5.0-sec, 12.5-ft waves, SWL = 1,850 ft

15. Reflection coefficients are shown in Figure 5 as a function of SWL. The figure shows high reflection at SWL = 1,846 ft, and a decreasing trend for higher water levels.

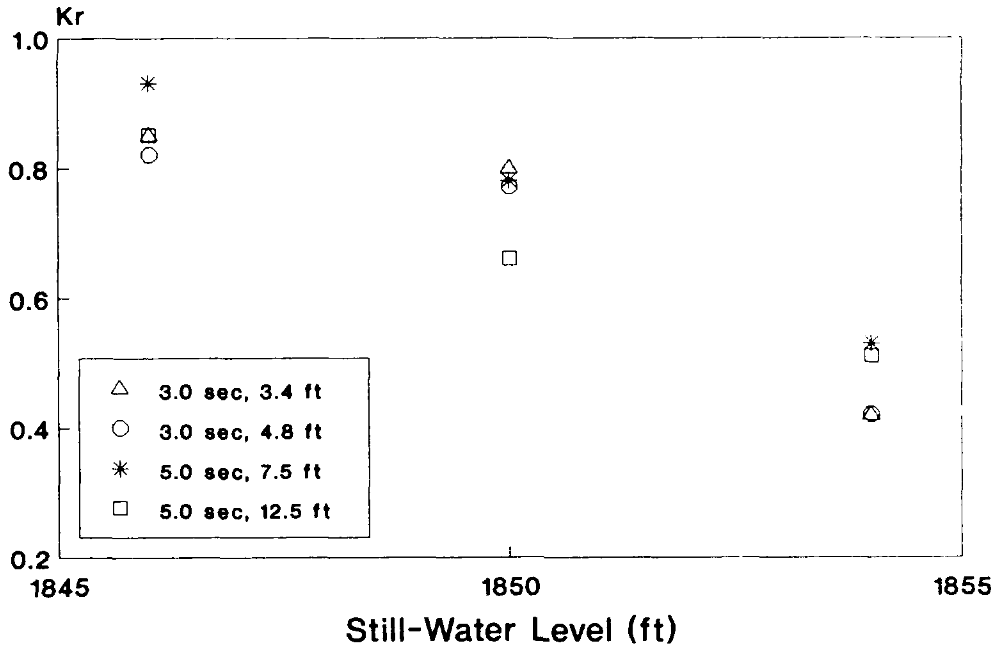

Figure 5. *Reflection as a function of SWL*

Maximum Free-Surface Water Elevation

16. The highest water elevation observed above the gate for each test was recorded. Figure 6 shows η_{max} plotted as a function of SWL. Maximum free-surface water elevation increases as SWL is raised from 1,846 ft to 1,850 ft and from 1,850 ft to 1,854 ft for the 3.0-sec waves. Maximum free-surface water elevation also increases as SWL is raised from 1,846 ft to 1,850 ft for 5.0-sec waves; however, η_{max} decreases as SWL is increased from 1,850 ft to 1,854 ft. Incident 5.0-sec waves at SWL =1,850 ft are reinforced by the combination of reflection, wave period, and water level, resulting in high water surface elevations over the gate. Although the water level was higher at SWL = 1,854 ft, reflection was less, and the reinforcing of reflected waves on incident waves observed at SWL = 1,850 ft did not occur. Incident waves at SWL = 1,846 ft were reinforced by reflection, but the SWL was low and η_{max} did not exceed the elevations observed at the other two water levels.

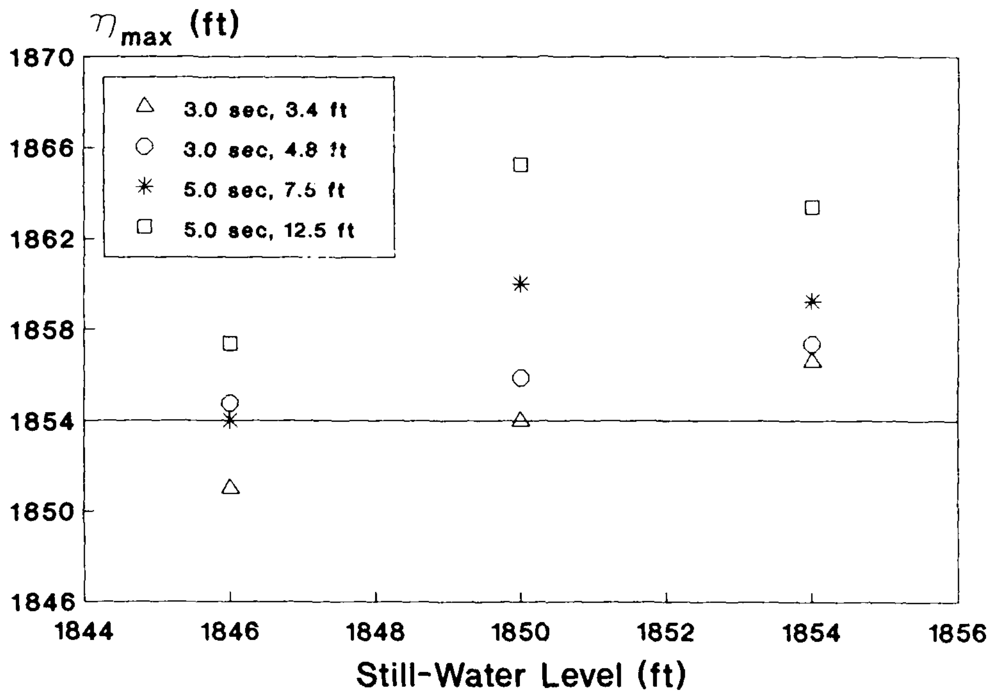

Figure 6. Maximum free-surface water elevation as a function o' SWL

PART IV: CONCLUSIONS

17. Results from the model study indicated that:

    a. Reflection was highest when the SWL was at the lowest level, SWL = 1,846 ft. The reflection coefficient was as high as 0.93 for the 5.0-sec, 7.5-ft wave condition.

    b. At the highest SWL, waves surged over the gate and reflection coefficients were in the range of 0.42 to 0.53.

    c. The maximum free-surface water elevation occurred at the 1,850-ft water elevation for 5.0-sec waves. The combination of water elevation, wave period, and wave reflection contributed to the higher elevation.

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APPENDIX A: NOTATION

A	Area
H	Wave height, feet
H/L	Wave steepness
K_r	Wave reflection coefficient
L	Length scale, feet; wave length, feet
r	Subscript denoting ratio of model to prototype
SWL	Still-water level, feet relative to mean sea level
T	Time scale, seconds; wave period, seconds
V	Volume
η_{max}	Maximum free-surface water elevation, feet relative to mean sea level